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Laser Beam Propagation through Long Ignition Scale Plasmas on NIF

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LASER BEAM PROPAGATION THROUGH LONG IGNITION SCALE PLASMAS ON NIF *

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LASER BEAM PROPAGATION THROUGH LONG IGNITION SCALE PLASMAS ON NIF

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Experiments on the National Ignition Facility (NIF) have employed the first four beams to measure propagation and laser backscattering losses in large ignition-size plasmas. Gas-filled targets between 2 mm and 7 mm length have been heated from one side by overlapping the focal spots of the four beams from one quad operated at 351 nm (3ω) with a total intensity of $2\text{x}10^{15}$W cm^{-2}. The targets were filled with 1 atm of CO_2 producing of up to 7 mm long homogeneously heated plasmas with densities of $n_e = 5 \text{ x } 10^{20}$cm^{-3} and temperatures of $T_e = 2$ keV. The high energy in a NIF quad of beams of 16kJ, illuminating the target from one direction, creates unique conditions for the study of laser plasma interactions at scale lengths not previously accessible.
The propagation through the large-scale plasma was measured with a gated x-ray imager that was filtered for 3.5 keV x rays. These data indicate that the beams interact with the full length of this ignition-scale plasma during the last ~1 ns of the experiment when applying full laser beam smoothing consisting of phase plates, smoothing by spectral dispersion and polarization smoothing. Measurements that only apply phase plates show laser beam filamentation and reduced propagation speed. These results demonstrate the NIF experimental capabilities and further provide a benchmark for three-dimensional modeling of the laser-plasma interactions at ignition-size scale lengths.

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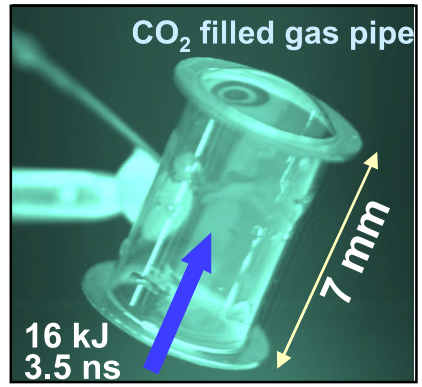
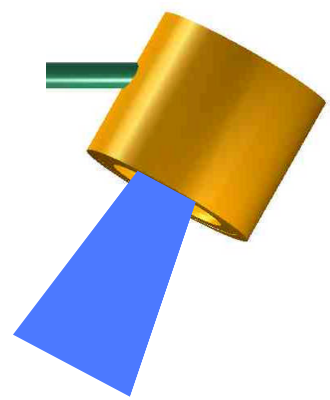
* Work performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract no. W-7405-ENG-48

Outline

- Introduction
  - National Ignition Facility
- Experiment
  - Laser Plasma interaction experiments on NIF
  - Long Pulse Vacuum Hohlraum Performance on NIF
- Results
  - Propagation through 7 mm plasmas
  - Hohlraum temperature scaling verified on NIF
- Conclusions



3.5 keV x-ray images showing beam propagation



Hohlraums perform like calorimeters for soft x radiation

On the first NIF experiments, we approach ignition size plasmas of 7mm length to study nonlinear interactions

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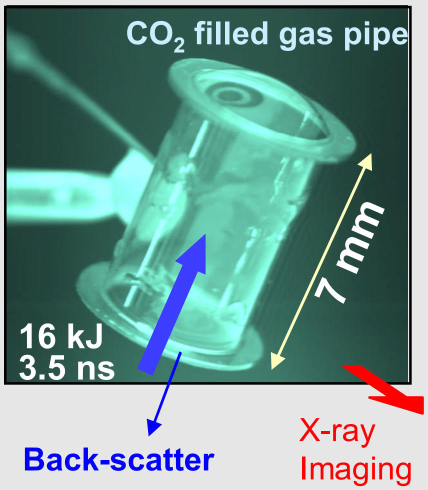
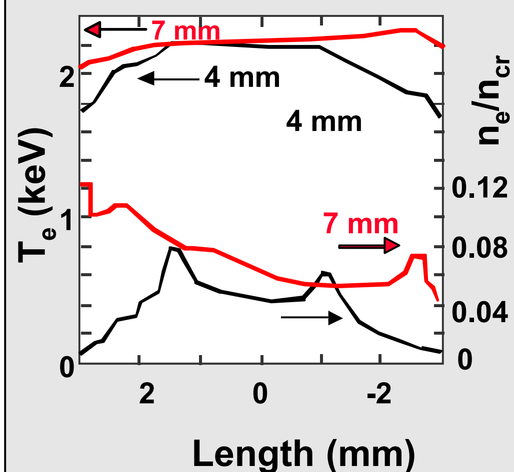
7 mm gas pipe target



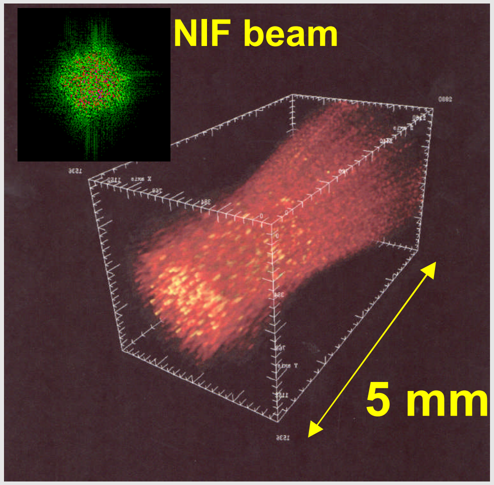
Measurements of propagation and laser back scatter

Calculated T_e, n_e profiles



Long homogeneous plasmas can be produced

Full pF3D calculation



Beam propagation through the plasma

- Plasmas allow study of backscatter with length at 2×10^{15} W cm^{-2}
  - not ignition surrogate (T_e lower, different species)
  - Low-T_e effects and filamentation (beam spray and self focusing) may be important
- Near backscatter imaging diagnostics was used to quantify scattering out side of FABS
- Effects of SSD and PS beam smoothing on beam propagation and stimulated scattering

The first four NIF beamlines have been commissioned to the center of the target chamber

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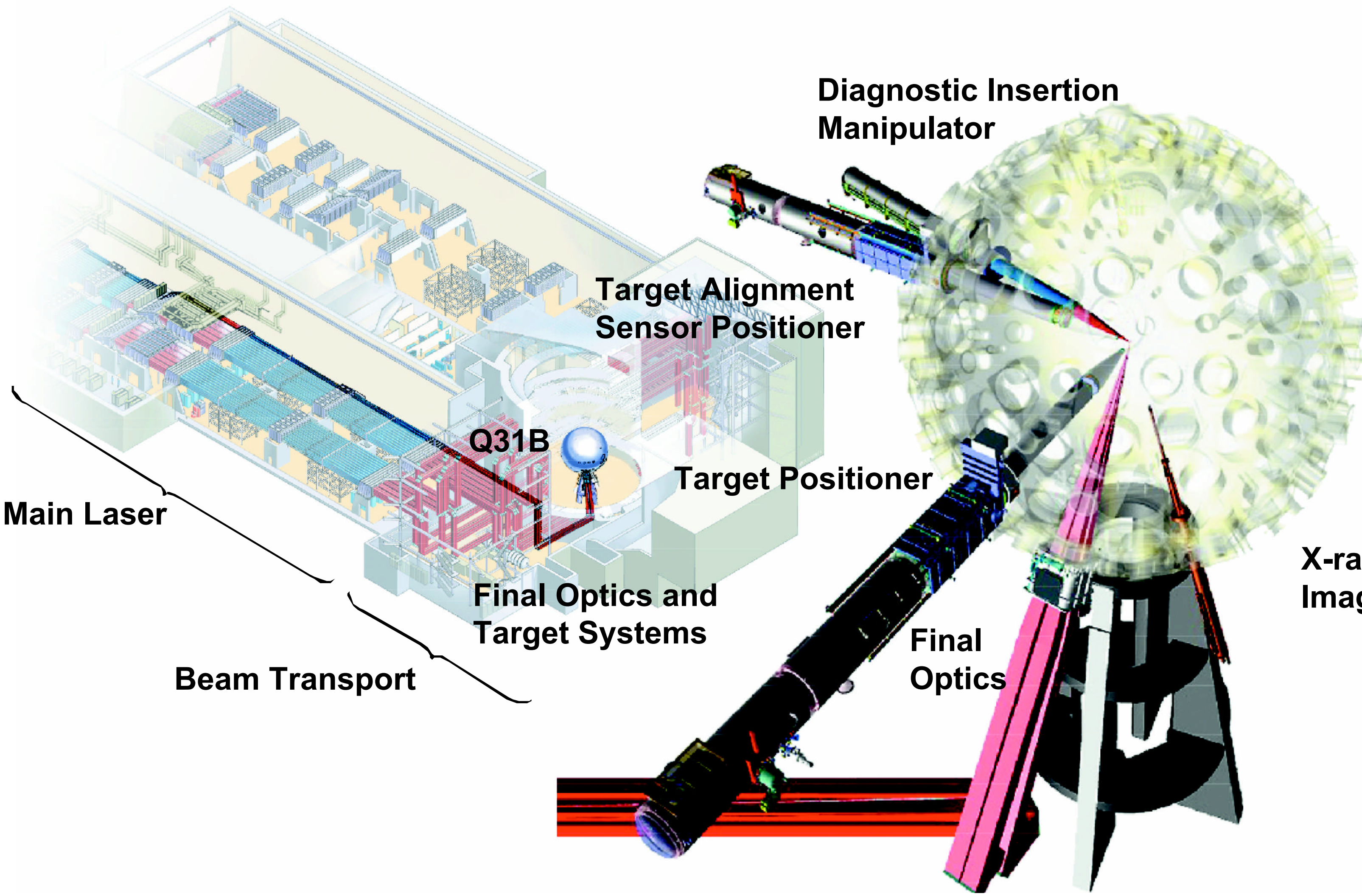
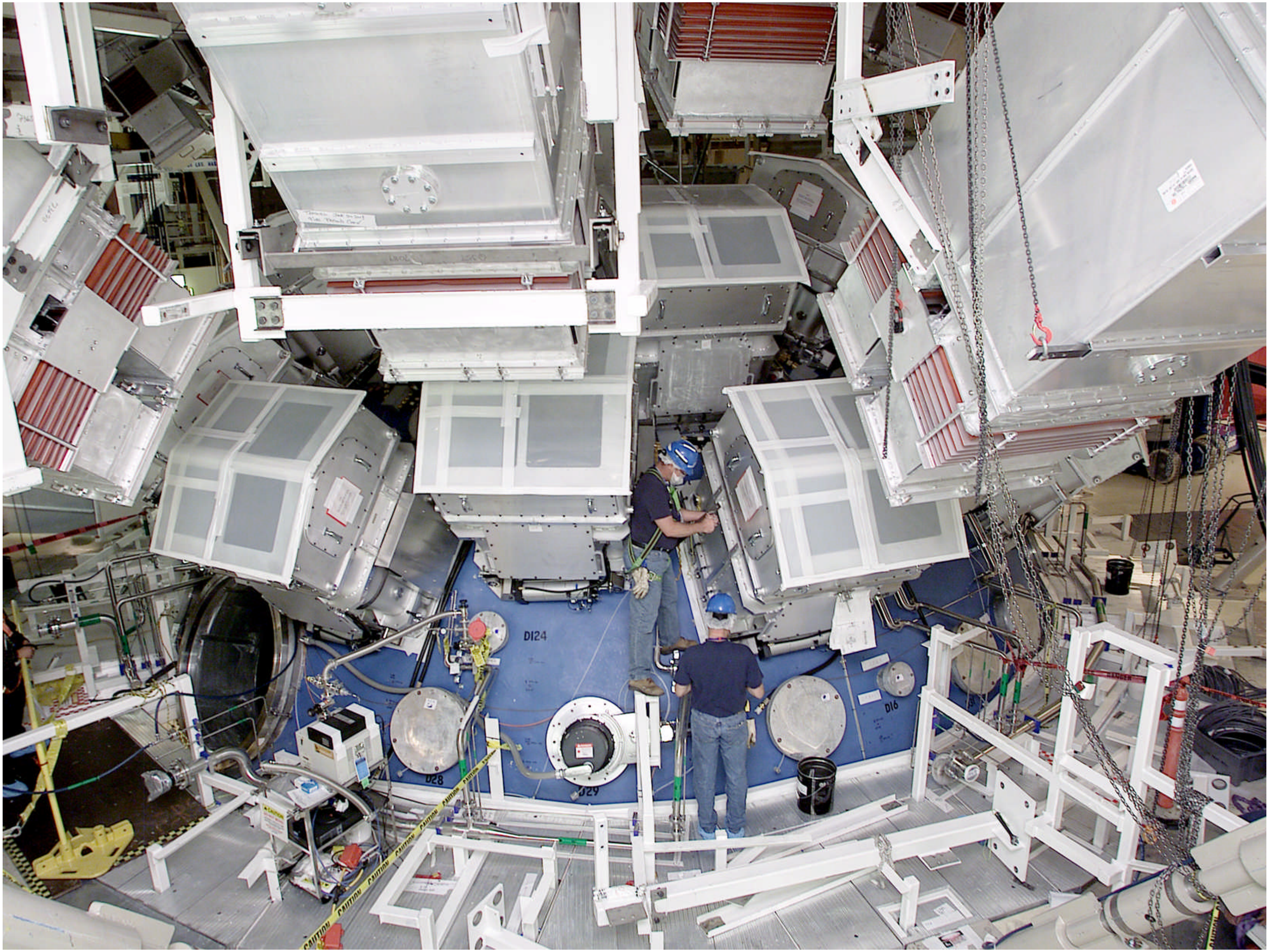
End-to-end functionality of all major subsystems demonstrated



The NIF beams are arranged in groups of 4 beams (quads)


D124
D16
D28
CAUTION

The first experiments on NIF have demonstrated control and suppression of filamentation in large scale plasmas

Experiment

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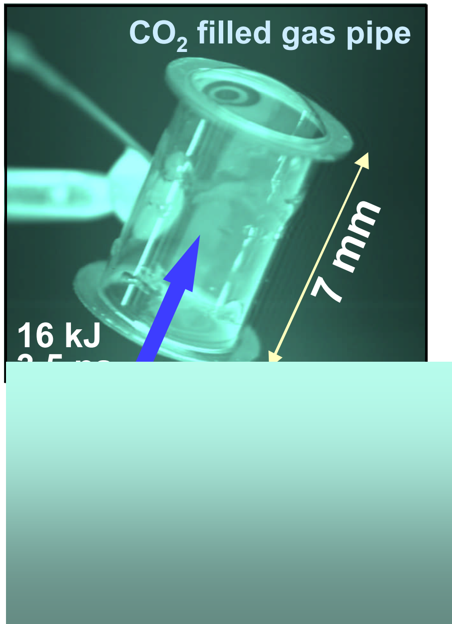
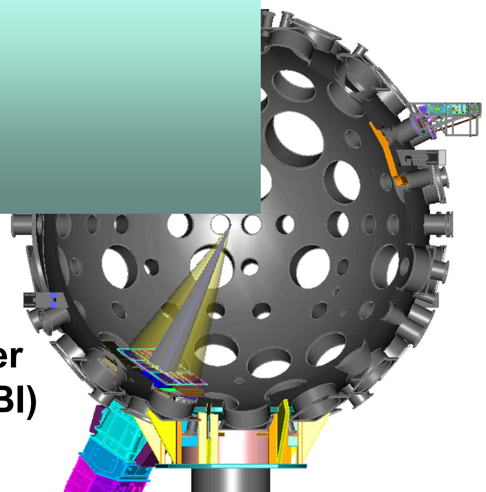
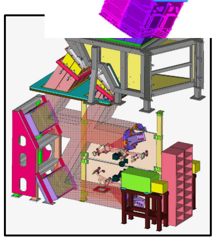
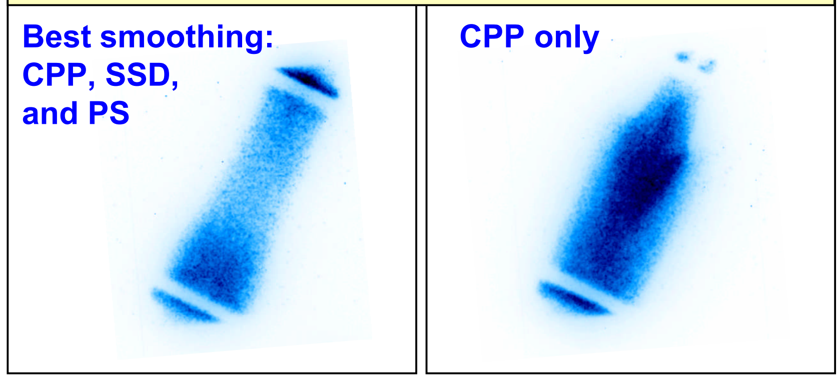


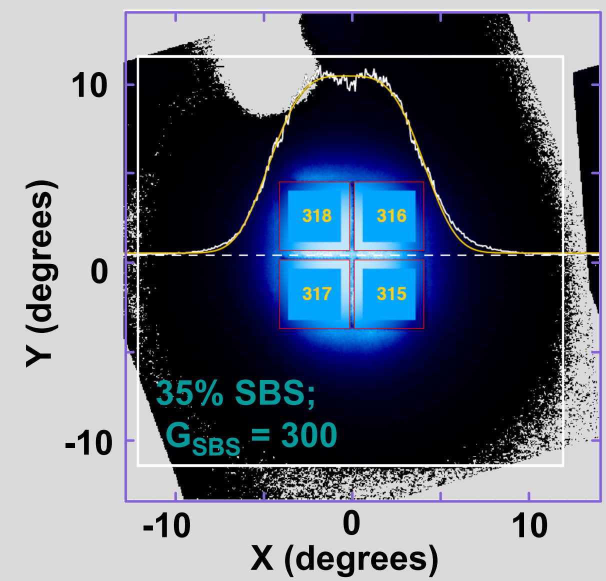


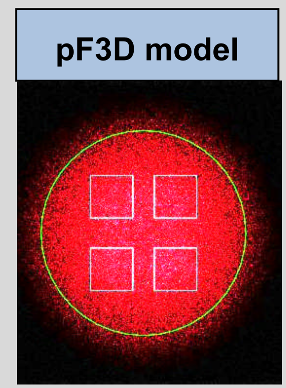


3.5 keV X-ray Images Showing Beam Propagation



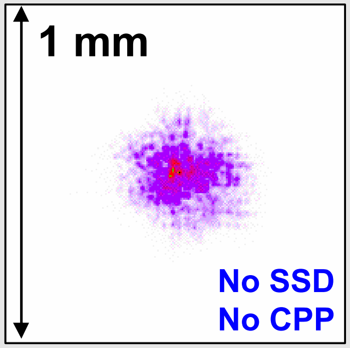
SBS and SRS Back-scatter Diagnostics Have Been Activated

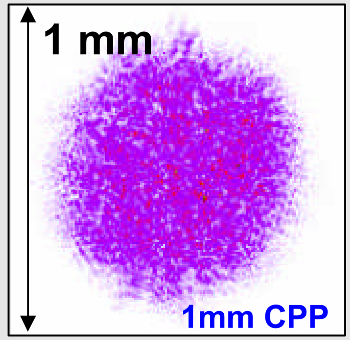


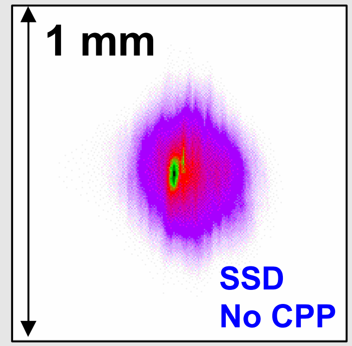


"Beam Smoothing" has several elements

No CPP	With CPP	With SSD
	Stationary speckles	Time-averaged pattern



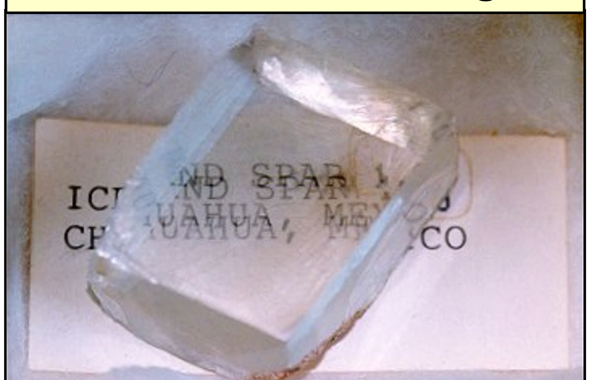




CPPs determine the spot size and the control intensity distribution

SSD moves hot spots on short time scales (~4 ps)

Polarization smoothing



Polarization smoothing separates the speckles giving instantaneous ~ $\sqrt{2}$ speckle intensity reduction

X-ray measurements of laser beams with PS, SSD indicate ideal propagation and agree with calculations to 0.3 ns

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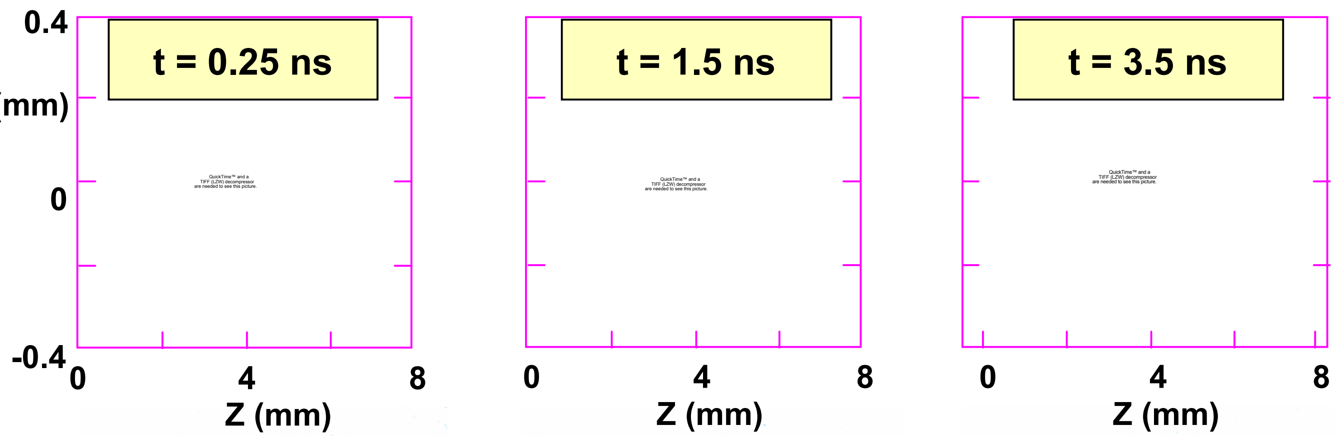
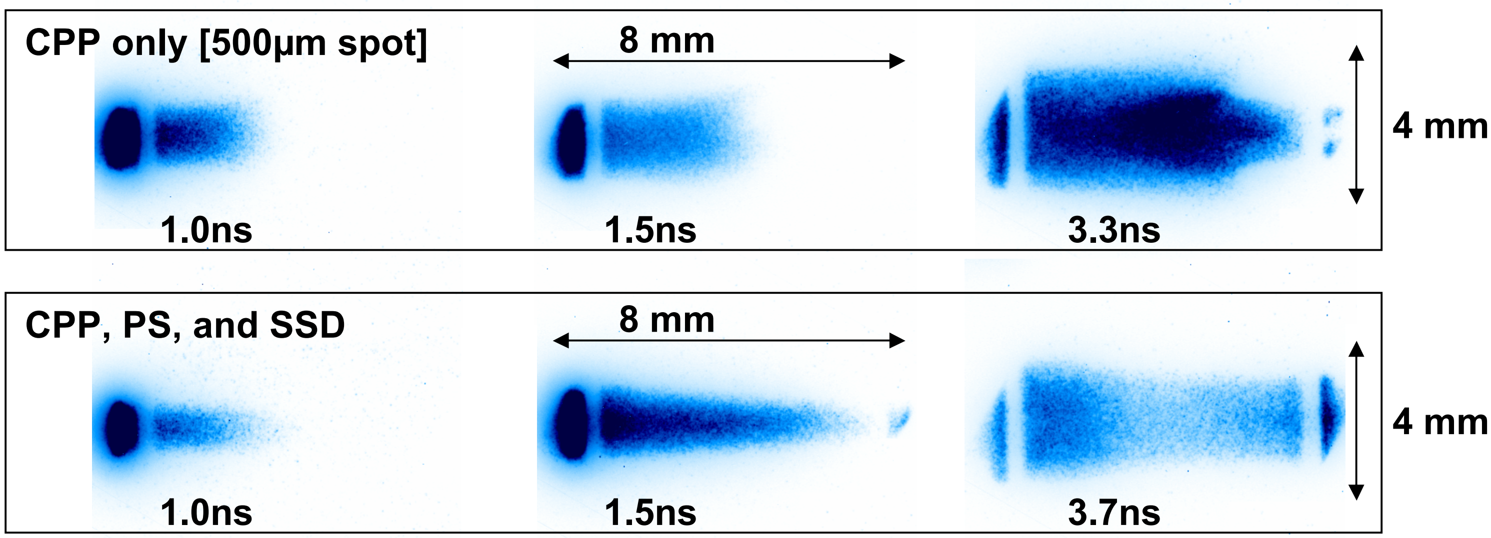
LASNEX





These propagation measurements are unique to NIF
These smoothing options will be fielded on full NIF ignition

Calculations with laser speckles and ponderomotive effects show improved propagation consistent with data

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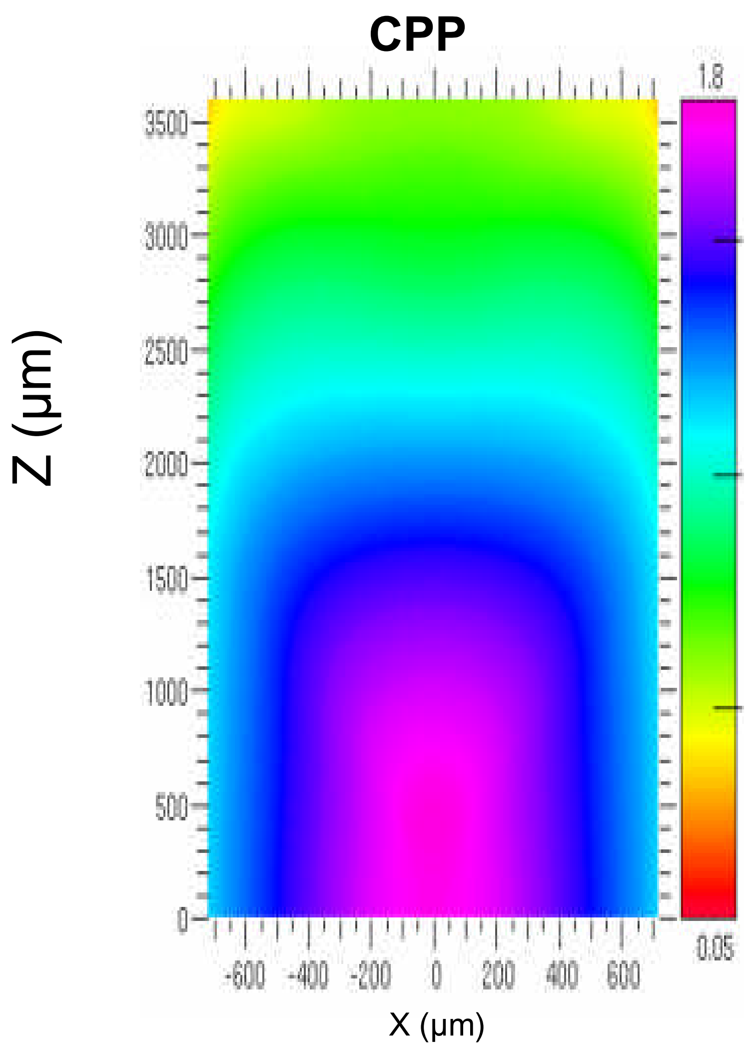

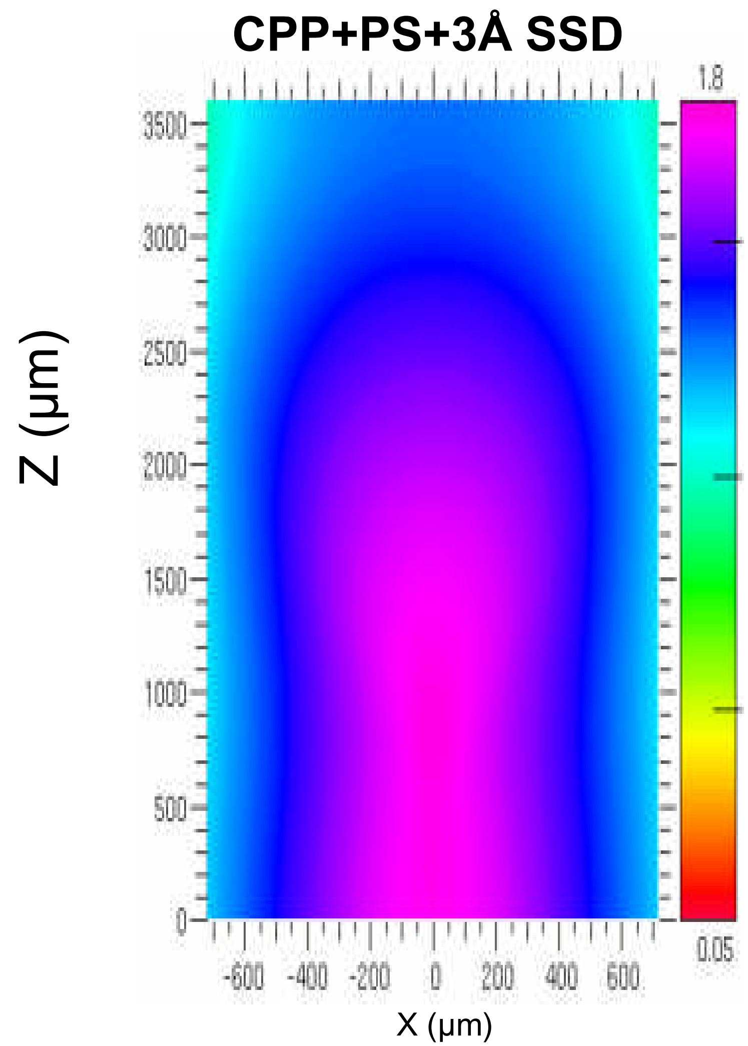

After 1ns, the fully smoothed beam has burnt through 1 mm farther

Experiment

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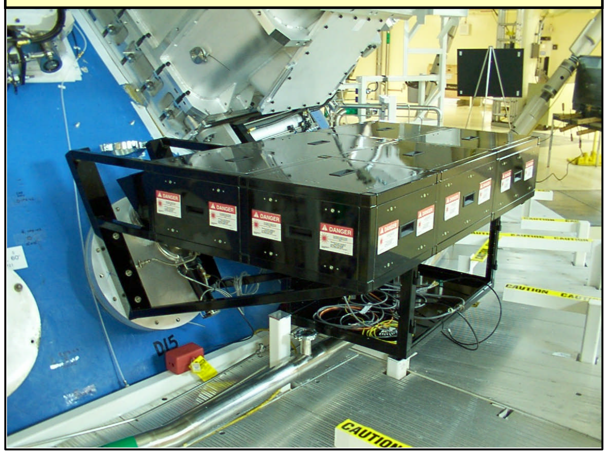
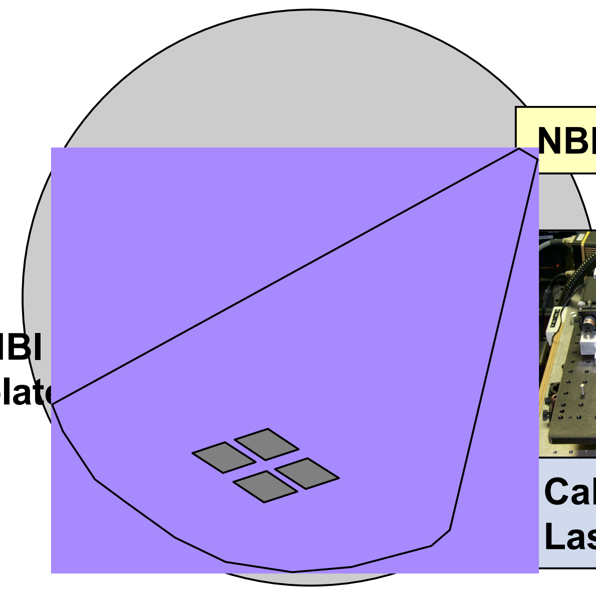
The NBI plate was calibrated at 351 nm and 527 nm and shown to be constant within ±10%

CCD cameras plus laser



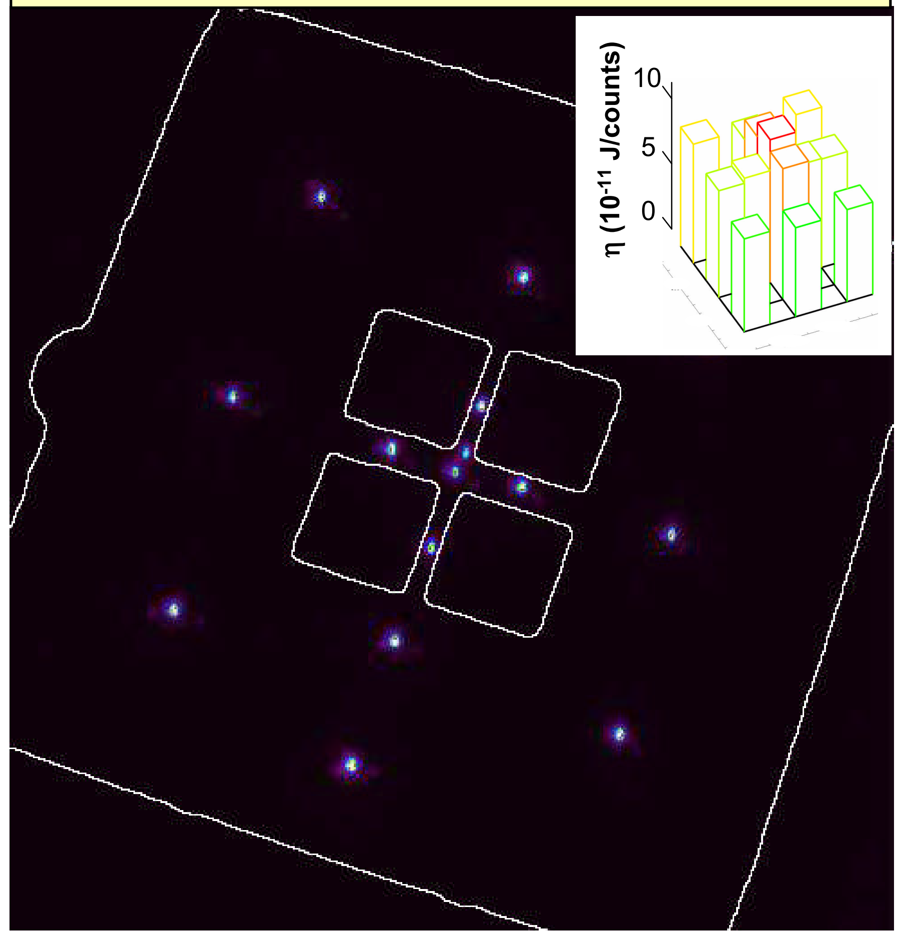
NBI plate



NBI system

Calibration Laser

NBI calibration laser measurements



- Sensitivity is slightly lower on the vertical cross
- Sensitivity is the same with and without acrylic

SBS Near backscatter imager shows more spray on shots without PS consistent with x-ray propagation

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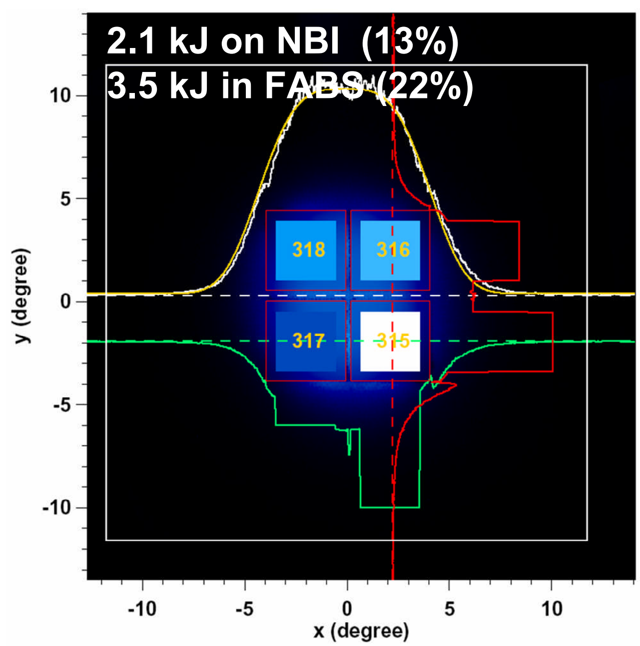
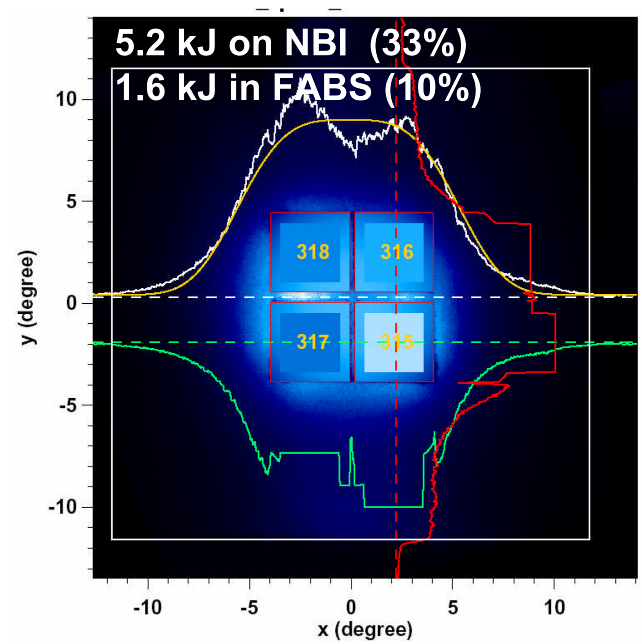
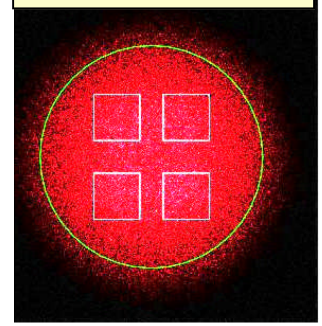
SBS with CPP+SSD+PS



SBS with CPP only



pF3D calculation of SBS: CPP

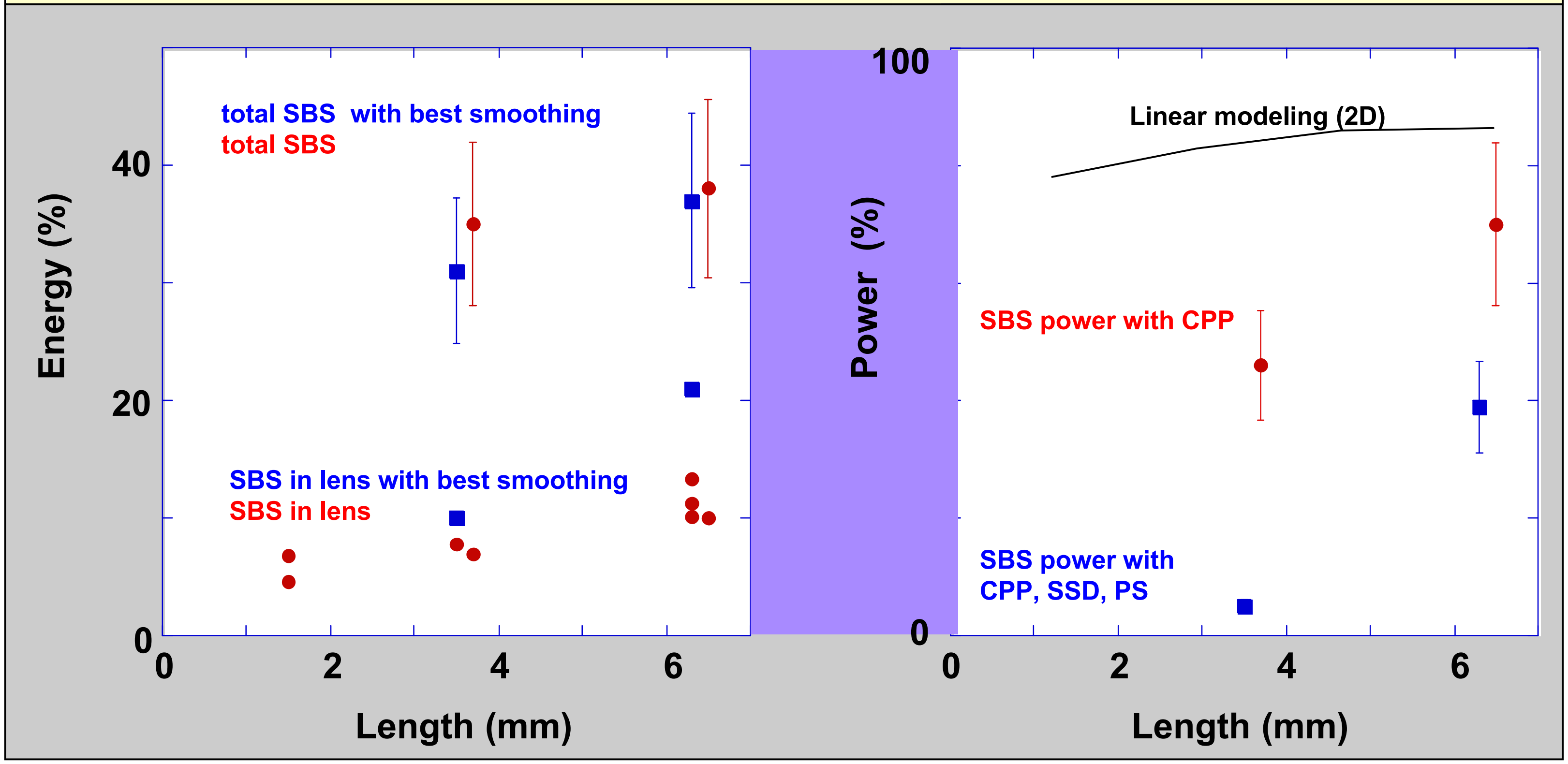


- SRS is negligible
- SBS Backscatter is more collimated with full beam smoothing
  - Spatial extend on scatter plate is reduced
  - Larger contribution into FABS
- Calculations slightly overestimate the amount of beam spray

The dependence of backscatter on plasma length shows nonlinear growth

SBS energy as function of plasma length

SBS power averaged over the last 1 ns of the experiment

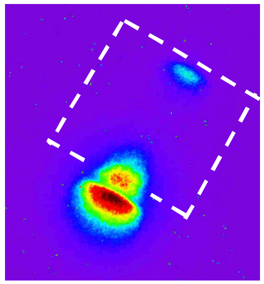


- We are in the process of modeling the backscattered SBS power
- To understand these results it will be important to properly model
  - Beam propagation, Filamentation, Nonlinear (kinetic) saturation processes
- Goal: predictive modeling for laser-plasma interactions in ignition conditions

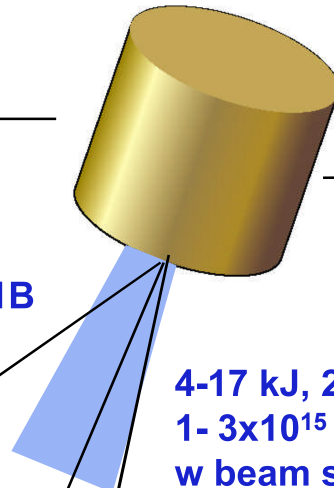
An international team has successfully activated hohlraum drive capability and related diagnostics at NIF

Results

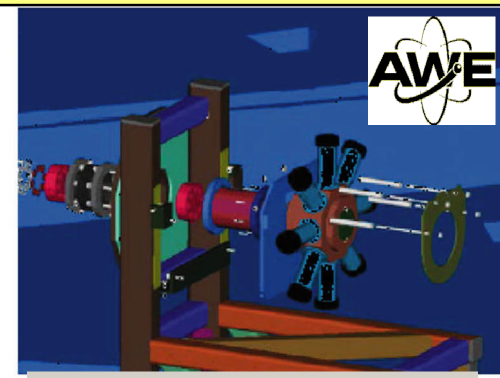
Plasma filling (10 keV x-ray imaging w/FXI)

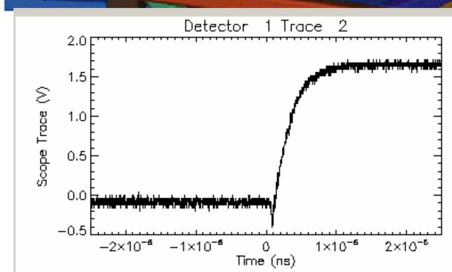


Thinwall Au Hohlraum



Hot electron production (AWE FFLEX)

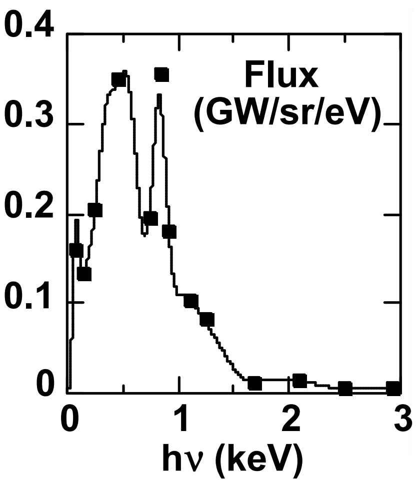


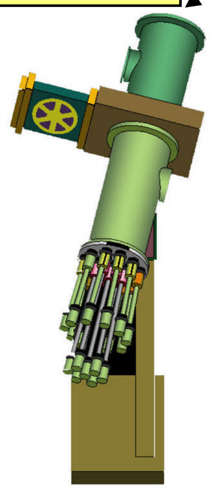


NIF Q31B

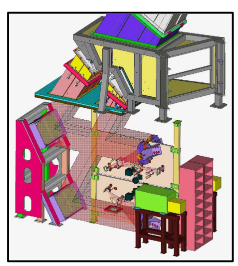
4-17 kJ, 2 - 9 ns,
1- 3x10^{15} W/cm^2
w beam smoothing

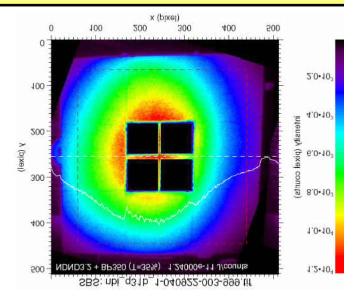
Hohlraum Temperature (Dante)





Laser Backscatter (FABS) and Near-Backscatter Imager (NBI)





Conclusions

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- Large scale length laser plasma experiments on NIF have demonstrated the importance of beam smoothing
  - Beams propagate through 7 mm of plasma with CPP, SSD, and PS
  - Backscatter during the last 1ns of the experiment is strongly affected by smoothing
  - It will be important to understand the late time SBS behavior
- The first hohlraum experiments on NIF have shown T_{RAD} > 300 eV
  - Hohlraum diagnostics activated
  - Results are in good agreement with modeling
  - No significant backscattering
- Future experiments may include
  - Gas-filled hohlraums versus lined hohlraums
  - Cocktails versus gold hohlraums
  - Relative merit of PS and SSD